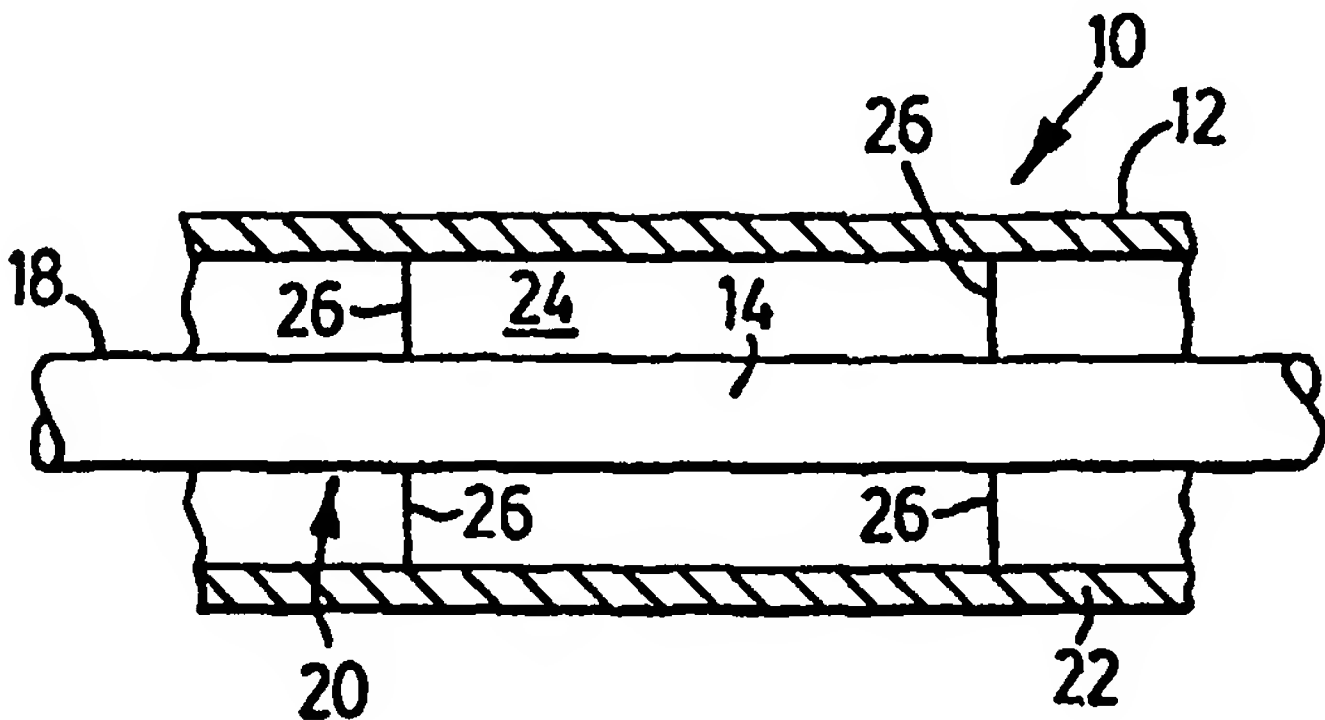


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<p>(54) Title: FREEZE PROTECTION APPARATUS FOR FLUID TRANSPORT PASSAGES</p> <p>(57) Abstract</p> <p>An elongated conduit (12) for conveying or containing liquid is provided comprising a flexible membrane (18), wherein the membrane (18) is disposed in substantially adjacent relationship with a compressible elastomeric material (14), the compressible elastomeric material (14) being supported by a permeable rigid support member (26). The membrane surface, adjacent to a second surface or the compressible elastomeric material, has a surface area exceeding the greater of (i) the area of the second surface when no liquid is in the conduit, and (ii) when the compressible elastomeric material is compressed due to freeze expansion.</p> 		

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FREEZE PROTECTION APPARATUS FOR FLUID TRANSPORT PASSAGES

Field of Invention

The present invention pertains to the field of freeze protection in fluid handling apparatus and, more particularly, to such freeze protection devices applied to solar thermal collectors and conduits.

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Background of the Invention

In colder climates where fluid carrying apparatus may be subjected to sub-zero temperatures, reliability of such equipment may be compromised by freeze damage. Under cold temperature conditions, working fluids comprised of aqueous liquids may freeze and, consequently, expand. If the working fluid is confined within rigid fluid passage walls, its expansion during freezing will be resisted. As a result, when freezing occurs, pressure increases within the fluid passage, which, depending on the rigidity, could lead to failure and rupture of the structure of the fluid passage after one or more freezing cycles.

Such reliability concerns exist with solar thermal collectors. The conversion of solar radiation to heat for building applications is achieved by circulating a working fluid, typically an aqueous liquid, through an arrangement of channels or like conduits or tubes that are typically in contact with a highly thermally conductive sheet whose selectively coated surface is exposed to the incident solar radiation. The heated fluid is then distributed to thermal storage and to building applications, such as space heating and domestic hot water heating. The actual solar radiation conversion device is a solar thermal collector.

Presently, three types of solar thermal collectors exist in building applications that embody the combination of a selectively coated sheet, or absorber sheet, and fluid-carrying channels or tubes. They are the flat plate collector, the heat pipe collector, and the evacuated tubular collector. Each type of collector can be divided into two functional zones: the collector absorber unit and the absorber unit encasement. The collector absorber unit consists of the assembly of the fluid carrying apparatus and the absorber sheet. Such working fluid carrying apparatus includes fluid passages defined by rigid walls for facilitating the transportation of the fluid through the collector absorber unit.

The prior art features several attempts to improve the ability of the collector absorber unit to endure conditions of fluid freezing for over 20 years of operation. Several means of dealing with the freezing of the working fluid have been proposed over the years by the solar industry, and by other fluid handling sectors as well.

5 In one method, water is removed from zones in the collecting apparatus where freezing conditions are expected. This strategy has been incorporated into the operation of drain-back and drain-down solar thermal systems. A control system signal initiates the removal of the fluid from the fluid passage that is exposed to the freezing conditions. In this case, reliability of the control system becomes critical. If the working fluid fails to be removed, then nothing protects the fluid
10 carrying apparatus from freezing damage.

In accordance with another method, fluids with freezing points that are lower than temperatures expected during operation are used. In general, such fluids are expensive, offer poor thermal properties, and involve high fluid handling costs. In all cases, they fail to provide significant gains in cost-effectiveness and do not justify their contribution to the prevention of freezing. Prime
15 examples of this method are the circulation of silicone oils or air in the solar thermal collector loop. Silicon oils are of high cost. They have thermal capacities which are lower than water. To match the thermal performance of the water, silicone oils must be circulated at high mass flows that cannot be justified because of the resultant increase in fluid handling costs, such as pump costs. Moreover, silicone oil is challenging to contain, thus necessitating additional cost-generating measures. Air
20 has a very low thermal capacity and low thermal conductivity and therefore, is only appropriate for space heating systems, which limits its scope of application.

A further means of preventing freeze damage is to inject chemical additives to lower the freezing point of the working fluid. The chemical stability of such mixtures is questionable over long operating periods, thus adding maintenance costs and creating new reliability concerns.
25 Moreover, this method must conform with local regulations relating to domestic water contamination, thus incurring additional costs. A conventional application of this method in solar thermal systems is the addition of propylene glycol to water. Historically, this mixture has been known to break down at collector stagnation temperatures while in the presence of oxygen. Without proper maintenance the propylene glycol mixture forms clumps and becomes corrosive over time,
30 which results in a loss of performance and capacity to protect from freezing.

Another means disclosed in the prior art is the use of a flexible and resilient insert inside the fluid channels of the solar thermal collector. Examples of such inserts are disclosed in U.S. Patent

Nos. 5,579,828; 4,227,512; 4,321,908; and 3,989,032. The insert can accommodate the expansion that the working fluid experiences upon freezing and thus protects the fluid carrying apparatus from rupturing. Although this design is very effective in freeze protection, it creates additional manufacturing costs (e.g. outfitting the fluid carrying apparatus with the insert). The operation of the insert is also plagued with reliability and durability concerns. Typically, the insert consists of a skin or sheath filled with a gas at a pressure higher than the working fluid pressure. The sheath or skin may be comprised of thin metal sheets, plastics, or elastomeric tubes. For a collector life that is expected to extend beyond the 20 year mark, flexible metallic inserts are unreliable because they will typically fail as a result of material fatigue, thermal aging, corrosion, or a combination thereof. Increasing the metal thickness to delay metal deterioration, due to corrosion or thermal aging, only increases the costs and curtails flexibility and capacity to accommodate the expansion of a freezing fluid. Over similar operating periods, plastic thin-walled inserts may get saturated with the working fluid since plastics are permeable to most fluids typically used in heat transfer applications. This renders the insert ineffective for freeze protection. In the case of solar thermal collectors, increasing the skin thickness to decrease permeability will unjustifiably increase the material costs since expensive high temperature plastics, such as Teflon™, are required to withstand stagnation conditions (which can exceed 200°C). Similar material costs and saturation issues apply to elastomeric inserts. Furthermore, thin walled pressurized designs, whether made of metal or plastic, are not robust because they are vulnerable to skin puncture, which subsequently renders the insert ineffective upon depressurization.

Other attempts in dealing with the freeze problem have included using conduits made with flexible and resilient walls to accommodate fluid expansion upon freezing, such as that disclosed in U.S. Patent 4,299,200. The walls of such conduits are made of plastics, elastomers, or metals, and therefore are similar to the materials used within the above-described inserts. As a result, this particular solution does not escape the same issues of robustness, material costs, metal fatigue, and corrosion which arise in association with the use of the insert. In addition, the use of plastics or elastomers as channel walls may impede performance of solar thermal collectors, or any heat exchanger application where this solution is incorporated because of the low thermal conductivity characteristics associated with such materials.

In yet another means of freeze protection, a controlled heat source is employed in the regions where freezing of the working fluid is anticipated. As in the first-mentioned prior art attempt at dealing with this problem, the reliability issue is not solved, but merely shifted to the operation and

control of the heat source. Further, with respect to solar thermal applications, this solution adds new components and thus additional costs.

Summary of Invention

5 The present invention discloses an apparatus for freeze protection of conduits used for the transportation of aqueous liquids.

 In one broad aspect, the present invention provides an elongated conduit for conveying or containing aqueous liquid, defining a liquid passage, comprising a first portion and a second portion, the first portion being a rigid wall and the second portion being a substantially liquid impermeable flexible membrane. The membrane is disposed in substantially adjacent relationship with a
10 compressible elastomeric material, the compressible elastomeric material being supported by a rigid support member having perforations for external drainage of liquid. The conduit can form part of a solar thermal collector. Further, the compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber and
15 urethane foam.

 In another aspect, the present invention provides an elongated conduit for conveying or containing aqueous liquid, defining a liquid passage, comprising a first portion and a second portion, the first portion being a rigid wall and the second portion being a substantially liquid impermeable flexible membrane, the rigid wall being attached to the flexible membrane wherein together they
20 form an outer perimeter of the liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material. The membrane has a first surface characterized by a first surface area, and the compressible elastomeric material has a second surface characterized by a second surface area. The first surface is in substantially adjacent relationship with the second surface. The first surface area exceeds the greater of the second surface area, when the
25 liquid passage contains no liquid and the compressible elastomeric material is in an uncompressed state or in a precompressed state, and the second surface area when the compressible elastomeric material is in its compressed state as a result of freeze expansion of the aqueous liquid.

 In another aspect, the present invention provides a conduit for conveying or containing aqueous liquids, comprising a substantially liquid impermeable flexible membrane for defining a
30 liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, the compressible elastomeric material being supported by a permeable rigid support member. The rigid support member can include perforation for external drainage of liquid.

In yet another aspect, the present invention provides a conduit for conveying or containing aqueous liquids, comprising a substantially liquid impermeable flexible membrane for defining a liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material. The membrane has a first surface characterized by a first surface area, and the compressible elastomeric material has a second surface characterized by a second surface area, the first surface being in substantially adjacent relationship with the second surface. The first surface area exceeds the greater of (i) the second surface area, when the liquid passage contains no liquid and the compressible elastomeric material is in an uncompressed state or in a precompressed state, and (ii) the second surface area when the compressible elastomeric material is in its compressed state as a result of freeze expansion of the aqueous liquid.

In yet a further aspect, the present invention provides a conduit for conveying or containing aqueous liquids comprising a substantially liquid impermeable flexible membrane for defining a liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material. The membrane includes a first portion and a second portion. An exterior of the first portion is disposed in substantially adjacent relationship with a first rigid structural support member and an exterior of the second portion is disposed in substantially adjacent relationship with a compressible elastomeric material.

In yet a further aspect, the present invention provides a conduit for conveying or containing aqueous liquids comprising a substantially liquid impermeable flexible membrane for defining a liquid passage. The membrane is disposed in substantially adjacent relationship with a compressible elastomeric material. The membrane and the compressible elastomeric material are supported by a rigid support member. The rigid support member is formed from a single sheet having a first edge and a second edge joined by a width. The single sheet is bent proximate the first edge to form a hem and a flap. The first edge is rolled over itself to form an interior rolled-over surface portion. The single sheet is further provided with a first bend along the width. The membrane and the compressible elastomeric material are substantially contained by the interior rolled-over surface portion. The first bend is disposed between the hem and the second edge. The flap is disposed within the first bend to form a lock. The first bend can join a first portion of the width to a second portion of the width, the first portion and the second portion extending from the first bend, the flap being inserted and pressed between the first portion and the second portion whereby the flap lockingly engages the first bend. The hem can contact a surface of the width to form a seam. The compressible elastomeric material can be disposed between the seam and the membrane. The lock

can be liquid permeable. The single sheet can be further provided with a second bend disposed between the first bend and the second edge, the second bend joining a third portion of the width to a fourth portion of the width, the third portion and the fourth portion extending from the second bend, the fourth portion forming an absorber plate in a solar thermal collector.

5 In a further aspect, the present invention provides a method of constructing a freeze protected conduit for conveying or containing aqueous liquids comprising the steps of (i) bending a single sheet having a first edge and a second edge joined by a width to form a hem and a flap proximate the first edge, (ii) rolling the first edge over itself to form an interior rolled-over surface portion, (iii) bending the sheet at a first point along the width between the hem and the second edge to form a first
10 bend, the first bend joining a first width portion and a second width portion, the first width portion and the second width portion extending from the first bend, (iv) inlaying a flexible conduit and compressible elastomeric material against the interior rolled-over surface portion for effecting containment and support of the flexible conduit and the elastomeric material, and (v) pressing the flap between the first width portion and the second width portion to form a lock. Step (iv) must
15 occur before step (v) and after step (ii), and wherein step (iii) must occur before step (v). The hem contacts a second point along the width of the sheet during step (ii).

In yet another aspect, the present invention provides a freeze protected conduit for conveying or containing aqueous liquids, defining a liquid passage, comprising a substantially liquid impermeable membrane disposed in substantially adjacent relationship with a compressible
20 elastomeric material, wherein the membrane comprises silicone rubber. The membrane has a thickness within the range of about 0.007 inches to about 0.020 inches. The conduit is used in heat transfer applications.

Brief Description of the Drawings

25 The invention will be better understood and objects other than those set forth above will become apparent when consideration is given to the following detailed description thereof. Such description makes reference to the annexed drawings wherein:

- Figure 1** is a side elevation sectional view of one embodiment of the present invention;
30 **Figure 2** is an end elevation sectional view of the embodiment illustrated in Figure 1;
Figure 3 is an end elevation sectional view of a second embodiment of the present invention;

- Figure 4** is an end elevation sectional view of another example of the second embodiment of the present invention;
- Figure 5** is an end elevation sectional view of a third embodiment of the present invention;
- Figure 6** is an end elevation sectional view of another example of the third embodiment of the present invention;
- Figure 7** is an end elevation view of another example of the second embodiment of the present invention where compressible elastomeric material is in its uncompressed or precompressed state;
- Figure 8** is an end elevation view of the embodiment illustrated in Figure 7, showing the compressible elastomeric material having adopted a concave profile after freeze expansion of liquid;
- Figure 9** is an end elevation view of a fourth embodiment of the present invention;
- Figure 10** is an end elevation view of a fifth embodiment of the present invention;
- Figure 11** is an end elevation view of a partial construction of the embodiment illustrated in Figure 10, showing such embodiment in the first stage of construction;
- Figure 12** is an end elevation view of a partial construction of the embodiment illustrated in Figure 10, showing such embodiment in the second stage of construction;
- Figure 13** is an end elevation view of a partial construction of the embodiment illustrated in Figure 10, showing such embodiment in the third stage of construction;
- Figure 14** is an end elevation view of a partial construction of the embodiment illustrated in Figure 10, showing such embodiment in the fourth stage of construction;
- Figure 15** is a pictorial flowsheet of a solar thermal collector process;
- Figure 16** is a side sectional view of a further embodiment of the present invention, as applied to a typical fluid passage within the solar thermal collector of Figure 15;
- Figure 17** is a side sectional view of a further embodiment of the present invention, as applied to a fluid passage between the absorber units within the solar thermal collector of Figure 15;
- Figure 18** is a side sectional view of the present invention as applied to the supply and return lines of the solar thermal collector of Figure 15;
- Figure 19** is a front sectional view of the application of the present invention illustrated in Figure 18, taken along line A-A thereof; and

Figure 20 is a front sectional view of the application of the present invention illustrated in Figure 18, taken along line B-B thereof.

Detailed Description of the Preferred Embodiment

5 Referring to Figures 1 and 2, a freeze protected conduit 10 of the present invention, having a length, comprises an elongated conduit 12 for conveying or containing aqueous liquid, and an elongated, compressible elastomeric material 14, less rigid than conduit 12, disposed within conduit 12 along the above-mentioned length.

10 The compressible elastomeric material, such as typified by numeral 14 in Figures 1 and 2, is comprised of resilient, compressible elastomeric material that has an elasticity that provides a stress-strain relationship which will keep stresses in the conduit 12 at levels below what would otherwise cause failure of conduit 12. The compressible elastomeric material 14 also has a shape memory which will provide freeze protection for the number of compression cycles anticipated over the operating life of the conduit 12. Examples of compressible elastomeric material 14 include
15 silicone foam, foamed butyl rubber, foamed neoprene, silicone sponge rubber, urethane foam, foamed EPDM, and other elastomers.

Preferably, the compressible elastomeric material 14 is fully sealed on all its sides and ends by a substantially liquid impermeable membrane 18 to form an insert 20 which is disposed inside of conduit 12. In this respect, membrane 18 behaves like a flexible wall which, along with rigid wall
20 22 of conduit 12, define an annular fluid passage 24.

Preferably, insert 20 is disposed along the axis of conduit 12, particularly where conduit 12 is used in heat transfer applications. Because the insert 20 is centrally located, it does not interfere with heat transfer between the conduit wall and the aqueous liquid in fluid passage 24 and is, therefore, particularly suitable for use in heat transfer applications, such as a solar thermal collector or photovoltaic cells. Referring particularly to Figure 2, insert 20 is retained in its generally central position within conduit 12 by the use of straps, splines or other supports 26 which supports insert 20 along its length. Preferably, such supports 26 will not be continuous but instead will be intermittent or spaced along the length of insert 20 so as to minimize interference with the flow or movement of liquid within conduit 12. In one embodiment, the present invention may be provided
25 with a plurality of splines 26 extending radially from insert 20 for biasing against the rigid wall 22 of conduit 12. Alternatively, splines 26 may extend radially inward from rigid wall 22 of conduit
30 of conduit 12.

12 for biasing against insert 20. In any event, use of the insert 20 can also be extended to any fluid handling apparatus that requires protection from fluid freezing damage.

Substantially liquid impermeable membrane, such as typified by numeral 18 in Figures 1 and 2, is generally constructed of a material that does not raise any corrosion, strength, chemical stability or thermal stability issues when operating in its working environment over the life of the apparatus. A choice for membrane material is a thin metal foil coated with a protective layer such as a plastic film. Another preferred choice is a thin, flexible, plastic membrane. Examples of plastic membrane materials include thermoplastics and elastomers. Polyesters, such as Kaladex™, and fluoropolymers, such as Teflon™ are choices of thermoplastics for a solar thermal collector environment. The preferred choice for membrane material is an elastomer, of which silicone rubber is a preferred example in solar thermal collector applications. The elastic nature of elastomers allows elastomeric membranes to possess thicker walls than membranes made of other material, such as thermoplastics. This greatly improves membrane robustness, and as a result improves the reliability of the membrane as a fluid containment component. Preferably, thickness of membranes used in the various embodiments of the present invention is within the range of about 0.007 inches to about 0.020 inches for elastomers, and 0.002 inches to 0.005 inches for thermoplastics, for optimal combination of heat transfer and reliable fluid containment.

When aqueous liquid in conduit 12 is subjected to freezing conditions, it will solidify and expand. As a result, compressible elastomeric material 14 deforms inwardly and becomes compressed to accommodate volumetric expansion of the freezing liquid in conduit 12 by effectively increasing the size of fluid passage 24. The compressible elastomeric material 14 is of such elasticity that it provides fluid passage 24 with the ability to increase its size. Without this ability for fluid passage 24 to increase in size, the freezing of liquid and consequent expansion (hereinafter also referred to as "freeze expansion") would create tensile such stresses in conduit 12, that could cause rupture of conduit 12. Upon thawing of the working fluid, the resilience of the compressible elastomeric material 14 enables it to spring back to its original shape. The compressible elastomeric material 14 has the additional advantage that it will not immediately lose its resiliency if the fluid permeates through membrane 18. In other words, if membrane 18 is punctured, the compressible elastomeric material 14 will not immediately lose its ability to assist in freeze protection.

In another embodiment of the present invention, particular examples of which are illustrated in Figures 3 and 4, an elongated conduit 28a, 28b is provided comprising a rigid wall 30a, 30b and a substantially flexible liquid impermeable membrane 32a, 32b, wherein rigid wall 30a, 30b is

connected to membrane 32a, 32b to form a fluid tight seal and define a fluid passage 34a, 34b. Membrane 32a, 32b is supported by compressible elastomeric material 36a, 36b, disposed substantially adjacent to the exterior surface 35a, 35b of membrane 32a, 32b. Supporting compressible elastomeric material 36a, 36b is support member 38a, 38b, wherein support member 38a, 38b is of greater rigidity than compressible elastomeric material 36a, 36b. Preferably, the compressible elastomeric material 36a, 36b is fully contained on all its sides and ends by support member 38a, 38b and membrane 32a, 32b.

In yet a further embodiment, examples of which are illustrated in Figures 5 and 6, a flexible conduit 40a, 40b, having a length, and defining a fluid passage 42a, 42b, is disposed within rigid structural support member 44a, 44b. Also disposed within rigid structural support member 44a, 44b, and in substantially adjacent relationship with exterior wall 41a, 41b of flexible conduit 40a, 40b is compressible elastomeric material 46a, 46b.

Flexible conduit 40a, 40b comprises a substantially liquid impermeable membrane 48a, 48b, which functions as a flexible wall of conduit 40a, 40b. Membrane 48a, 48b is disposed in substantially adjacent communication with either of rigid structural support member 44a, 44b or compressible elastomeric material 46a, 46b, thereby receiving structural support from either or both of member 44a, 44b and material 46a, 46b. Preferably, flexible conduit 40a, 40b and compressible elastomeric material 46b, 46b are fully contained by rigid structural member 44a, 44b.

To further protect any of membranes 18, 32a, 32b, or 48a, 48b in the corresponding embodiments illustrated in Figures 1, 2, 3, 4, 5 or 6 from tensile forces caused by freeze expansion, the surface area of the membrane 18 (32a, 32b, 48a, 48b) is preferably of a sufficient size. In this respect, depending on the geometry of the compressible elastomeric material 14 (36a, 36b, 46a, 46b), the size of the surface area of a first surface of the membrane 18 (32a, 32b, 48a, 48b) in substantially adjacent relationship with a second surface compressible elastomeric material 14 (36a, 36b, 46a, 46b), preferably, exceeds the greater of:

- (i) the surface area of the second surface of compressible elastomeric material 14 (36a, 36b, 46a, 46b) when the liquid passage contains no liquid and compressible elastomeric material 14 (36a, 36b, 46a, 46b) is;
 - a) in an uncompressed state, or
 - b) in a precompressed state and

- (ii) the surface area of the second surface of compressible elastomeric material 14 (36a, 36b, 46a, 46b), when compressible elastomeric material 14 (36a, 36b, 46a, 46b) is in its compressed state as a result of freeze expansion.

To further illustrate how geometry of compressible elastomeric material 14 (36a, 36b, 46a, 46b) dictates the preferred choice of membrane 18 (32a, 32b, 48a, 48b) surface area, an embodiment of the present invention depicted in Figure 4 shows compressible elastomeric material 36b of a geometry wherein that part of its surface in substantially adjacent relationship to membrane 32b (hereinafter, "the operative surface area") is of a convex profile relative to membrane 32b. In this case, as compressible elastomeric material 36b deforms and compresses to facilitate freeze expansion in fluid passage 34b, the operative surface area becomes smaller. Therefore, in this case, to assist in preventing membrane 32b from experiencing tensile forces, surface area of membrane 32b should, preferably, exceed the operative surface area of compressible elastomeric material 36b when in its uncompressed state (ie. the condition where such operative surface area is at its largest point).

In other geometries, an example of which is illustrated in Figure 3, the operative surface area of compressible elastomeric material 36a is largest when the compressible elastomeric material 36a is in its compressed state. In such cases, the surface area of membrane 32a should, preferably exceed that of the operative surface area of the compressible elastomeric material 36a when in its compressed state as a result of freeze expansion.

As a further illustrative example, an embodiment of the present invention depicted in Figure 7 shows compressible elastomeric material 36c of a geometry wherein its operative surface area is, at least initially, of a convex profile relative to membrane 32c of conduit 28c. Conduit 28c comprises membrane 32c and rigid wall 30c. In this case, as compressible elastomeric material 36c deforms and compresses to facilitate freeze protection in fluid passage 34c defined by conduit 28c, the operative surface, at first, becomes smaller. As freeze expansion continues, the operative surface area of the compressible elastomeric material 36c eventually adopts a concave profile (see Figure 8). At this point, as freeze expansion continues, the operative surface area proceeds to become incrementally larger. In this case, the operative surface area of the compressible elastomeric material 36c could be greater when compressible elastomeric material 36c is either (i) in an uncompressed or pre-compressed state, or (ii) a compressed state. This would depend on the relative geometries of the fluid passage 34c, membrane 32c, compressible elastomeric material 36c, and structural

support member 38c. To minimize risk of failure of membrane 32c due to tensile forces, therefore, the surface area of the membrane 32c should exceed such greater value of the operative surface area.

Referring to Figure 3, in another embodiment of the present invention, support member 38a may include perforations 39 for permitting evaporation of aqueous liquid which may permeate through membrane 32a and become entrapped in compressible elastomeric material 36a. Permeation of aqueous liquid is of particular concern where membrane 32a is of a plastic material and therefore more likely to permit ingress of aqueous liquid from fluid passage 32a into compressible elastomeric material 36a. Failure to facilitate removal of the aqueous liquid from the compressible elastomeric material 36a could compromise freeze protection efficacy of the present invention. As a necessary incident of this, it is preferable for the compressible elastomeric material 36a to be of an open cell construction to facilitate diffusion of the aqueous liquid.

Figure 9 illustrates a further embodiment of the present invention, where rigid structural support member 44c also include perforations 49 for external drainage of liquid trapped in compressible elastomeric material 46c. The difference between the embodiment illustrated in Figure 3 and that which is illustrated in Figure 9 is the fact that the fluid conduit 40c of the embodiment in Figure 9 is completely defined by a flexible membrane 48c.

It is understood that the use of perforated or liquid permeable support members is not limited to the embodiments illustrated in Figures 3 and 9, and could be used in other variations of the present invention wherever support members are used to support compressible elastomeric material of the present invention, so long as the support member does not form part of the fluid containment structure, such variations including the embodiments depicted in Figures 4, 5, 6, 7 and 8.

Figures 10 - 14 are illustrative of a method of constructing an embodiment of the present invention having a rigid structural support member 110 comprising a seam 112 and a lock 114. Rigid structural support member 110 is formed from a single thin metal sheet 116, preferably of copper or aluminum. Sheet 116 comprises a first edge 126a and a second edge 126b, the first and second edges 126a and 126b being connected by a width 134. A preferred thickness of sheet is 0.005 inches to 0.012 inches to provide for a desired combination of strength, heat transfer, manufacturability, and material cost features. Rigid structural member 110 supports compressible elastomeric material 118. Each of rigid structural support member 110 and compressible elastomeric material 118 supports flexible fluid conduit 120. Conduit 120 is comprised of flexible membrane 122, and defines fluid passage 124.

Referring to Figures 11 - 13, as a first step, first edge 126a of sheet 116 is bent into a hem 128, thereby forming a flap 130 (see Figure 11) then rolled over itself and forming an interior rolled-over surface portion 132, thereby substantially defining the perimeter of rigid structural support member 110 (see Figure 12). The remaining width 134 of sheet extending from second edge is available to produce a first bend 136 and a second bend 138 (see Figure 13). First bend 136 joins a first portion 137a of width 134 to a second portion 137b of width 134, the first portion 137a and the second portion 137b extending from first bend 136. First bend 136 and second bend 138 are provided for engaging flap 130, thereby forming lock 114. Before engaging flap 130 with first and second bends 136 and 138, flexible conduit 120 and compressible elastomeric material 118 are inlaid against interior rolled-over surface portion 132 (see Figure 13). Once flexible conduit 120 and compressible elastomeric material 118 are disposed in this manner, flap 130 is pressed into first bend 136, between first portion 137a and second portion 137b, and then hem 128 is pressed against a point 129 on a surface of width 134 of sheet 116 to form seam 112 (see Figure 14). Second bend 138 is then pressed against flap 130, thereby forming lock 114 (see Figure 10). Lock 114 enables the rigid structural support member 110 to resist internal fluid pressure that is transmitted through flexible conduit 120 and compressible elastomeric material 118. Preferably, once the flap 130 is locked in place, hem 128 is rolled over itself a full 360 degrees.

It is understood that formation of bends 136 and 138 can occur before the rolling of first edge 126a over itself, or even before formation of hem 128 and flap 130. Further, it is understood that flexible conduit 120 and compressible elastomeric material 118 can be inlaid against interior rolled-over surface portion 132 immediately after rolling of first edge and before formation of bends 136 and 138.

In one embodiment, any available sheet material width 134 extending between the second bend 138 and the second edge 126b could be used to form an absorber plate in a solar thermal collector. In this respect, second bend 138 joins third portion 139a of width 134 and fourth portion 139b of width 134. The third and fourth portions 139a and 139b extend from second bend 138 in different directions. The fourth portion 139b has an available surface for forming an absorber plate in a solar thermal collector.

In one embodiment, the seam 112 and lock 114 formed in rigid structural support member 110 do not provide 100% fluid containment of any moisture which may become trapped in compressible elastomeric material. Seam 112 and lock 114 are not fluid tight but are, rather, permeable, thereby permitting the compressible elastomeric material 118 to breathe and facilitating

external drainage of liquid which may ingress into compressible elastomeric material 118 from fluid conduit 120. In other words, rigid structural support member 110 and compressible elastomeric material 118 do not form a closed system.

In one embodiment, and as illustrated in Figure 10, compressible elastomeric material 118 is disposed between seam 112 and flexible conduit 120. Positioning compressible elastomeric material 118 in this manner minimizes the risk of generating stress risers in flexible conduit 120 and further minimizes the risk of having flexible conduit 120 pry seam 112 open under the action of internal fluid pressure, which may eventually cause failure of lock 114 or flexible conduit 120.

The above-described freeze protection means is not limited to straight lengths of conduits, as may be suggested by the embodiments illustrated in Figures 1 - 10. Because of the flexibility of the compressible elastomeric material and substantially liquid impermeable membrane, and particularly the unpressurized state of compressible elastomeric material, compressible elastomeric material and substantially liquid impermeable membrane can be readily adapted for use in bends, such as elbows or tees.

In one application, the present invention may be used within a fluid handling apparatus for absorbing heat in a solar thermal collector. Generally, depending on the climatic region, solar thermal collectors are exposed to cold temperature conditions. As a result, the working fluid, which is typically an aqueous liquid, circulating through the conduit, is susceptible to freezing and consequent expansion, thereby threatening the integrity of the walls of the conduit. Accordingly, solar thermal collectors would benefit from the freeze protection offered by the apparatus of the present invention.

Figure 15 illustrates a pictorial flowsheet of a typical solar thermal collector 50, used on the roof 52 (or facade) of a typical building structure, comprising an array of individual collectors 56, absorber units 58 associated with each collector 56, and a storage vessel 60 for containing working fluid which is circulated through collector 50. Motive means 62, such as a pump, are provided to recirculate working fluid from storage vessel 60, through collector 50, and back to storage vessel 60. Motive means 62 draws working fluid from storage vessel 60 and introduces working fluid to collector 50 via supply line 64. Supply line 64 is connected to the supply manifold 66 of collector 50 for distribution to individual absorber units 58. Supply manifold 66 supplies working fluid to absorber units 58 by connection to supply header 68 of an absorber unit 58. Working fluid is conducted through each absorber unit 58 through a plurality of closely spaced elongated piping 70 which are connected to supply header 68, and discharge into discharge header 72. Discharge header

72 may be connected to supply header 68 of another absorber unit 58 or may directly discharge to return manifold 74 for return to storage vessel 60 via return line 76.

Alternatively, aqueous fluid may be conducted through solar thermal collector 50 by a single conduit. In this respect, conduit would be connected at one end to supply line 64, and to return line 76 at the other end. Within each absorber unit 58, conduit would adopt a generally serpentine geometry as a mean of enhancing heat transfer efficiencies.

Referring to Figures 15 and 16, working fluid which travels through piping 70 in any of the absorber units 58 are in contact with absorber sheet 78. Absorber sheet 78 is exposed to and absorbs incident solar radiation, thereafter converting such radiation to heat and conducting such heat to the working fluid circulating within piping 70. Heated aqueous liquid is discharged into return line 76 to be returned to storage vessel 60. Heated water in storage vessel 60 may be subsequently used as a source of domestic hot water supply or as a heat source for various applications, such as for space heating or pool heating, or could be used in commercial applications and industrial processes.

Every fluid passage in solar thermal collector 50 may be adapted for use with the freeze protection apparatus of the present invention. Referring to Figures 15 and 16, a section of a typical fluid passage 80 is shown adapted for use with the freeze protection apparatus of the present invention by defining such fluid passage 80 with flexible conduit 82 wherein flexible conduit 82 is disposed within rigid structural support member 84. Also disposed within rigid structural support member 84 is compressible elastomeric material 88.

Rigid structural support member 84 comprises absorber sheet 78 and undercarriage 90. Absorber sheet 78 is connected to undercarriage 90 to cause containment of flexible conduit 82 and compressible elastomeric material 88.

Flexible conduit 82 comprises a substantially liquid impermeable membrane 92, which functions as a flexible wall for conduit 82, and includes an upper wall 94 and a lower wall 96. Upper wall 94 is disposed in substantially adjacent relationship with absorber sheet 78, thereby receiving structural support from absorber sheet 78. Additionally, such configuration facilitates conductance of heat from absorber sheet 78 to aqueous liquid in fluid passage 80 of conduit 82. Lower wall 96 is disposed in substantially adjacent relationship with compressible elastomeric material 88, thereby receiving structural support from compressible elastomeric material 88.

For further illustration, Figure 17 shows a fluid passage 80a within collector 50 (Figure 16) between adjoining first absorber unit 58a and second absorber unit 58b. Fluid passage 80a connects discharge header 72 of first absorber unit 58a with supply header 68 of second absorber unit 58b.

As any typical fluid passage 80 (Figure 16) in collector unit 50, fluid passage 80a is defined by flexible conduit 82, disposed within rigid structural support member 84. Also disposed within rigid structural support member 84 is compressible elastomeric material 88. In this respect, flexible conduit 82 is supported by rigid structural support member 84 and compressible elastomeric material 88.

Fluid passages between the collector unit 50 and supply line 64 (Figure 15), including supply manifold 66, and within supply line 64, may be exposed to cold temperature conditions to some extent. The same is true with respect to fluid passages between collector unit 50 and return line 76, including return manifold 74, and within return line 76. In this respect, where such fluid passages are exposed to cold temperature conditions, the corresponding conduit is protected from freeze damage by the present invention.

Figures 18, 19 and 20 illustrate a typical fluid passage 90 between exterior to collector 50, and is representative of the connection of collector 50 to supply line 64, or the connection of collector 50 to return line 76. Flexible conduit 92 is provided to define fluid passage 90 where fluid passage 90 may be exposed to cold temperature conditions. Accordingly, with respect to the solar thermal collector system in Figure 6, flexible conduit 92 is provided in fluid passages connecting supply header of absorber unit 58a to supply manifold, and extend into supply line 64 where freeze damage is a concern. Similarly, flexible conduit 92 is provided in fluid passages connecting discharge header of absorber unit 58c to return manifold, and extend into return line 76 where freeze damage is a concern.

Flexible conduit 92 comprises a substantially liquid impermeable membrane 94 and is disposed within rigid structural support member 96. Also, disposed within rigid structural support member 96 is compressible elastomeric material 98. In this respect, flexible conduit 92 is supported by rigid structural support member 96 and compressible elastomeric material 98.

Where freeze damage is no longer a concern, with respect to supply line 64 or return line 76, supply line 64 or return line 76 comprises a rigid conduit 100. Rigid conduit 100 is connected in fluid tight manner with flexible conduit 92 at a location where freeze damage is not a concern. Beyond this point, freeze protection apparatus of the present invention is no longer required. In this respect, referring particularly to Figures 18, 19 and 20, compressible elastomeric material 98 will terminate longitudinally at end plate 102 which forms part of rigid structural support member 96.

While one application of the present invention has been described with respect to solar thermal collection 50, it should be readily understood that the present invention is equally applicable

to a liquid containing conduit or other apparatus which is subject to freezing in heat transfer and non-heat transfer processes. As a further example of its application to a heat transfer process, the present invention may be used as a means of absorbing heat from a photovoltaic cell.

5 It will be understood, of course, that modifications can be made in the embodiments of the invention illustrated and described herein without departing from the scope and purview of the invention as defined by the appended claims.

We claim,

1. An elongated conduit for conveying or containing aqueous liquid, defining a liquid passage, comprising a first portion and a second portion, the first portion being a rigid wall and the second portion being a substantially liquid impermeable flexible membrane, wherein said membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, said compressible elastomeric material being supported by a rigid support member, said rigid support member being liquid permeable.
2. The conduit of claim 1, wherein said rigid support member comprises perforations for facilitating external drainage of liquid.
3. The conduit of claim 1, wherein said conduit forms part of a solar thermal collector.
4. The conduit of claim 1, wherein said compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber, foamed EPDM, and urethane foam.
5. An elongated conduit for conveying or containing aqueous liquid, defining a liquid passage, comprising a first portion and a second portion, the first portion being a rigid wall and the second portion being a substantially liquid impermeable flexible membrane, said rigid wall being attached to said flexible membrane wherein together they form an outer perimeter of said liquid passage, wherein said membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, wherein said membrane has a first surface characterized by a first surface area, and said compressible elastomeric material has a second surface characterized by a second surface area, said first surface being in substantially adjacent relationship with said second surface, said first surface area exceeding the greater of:
 - (i) said second surface area, when said liquid passage contains no liquid and said compressible elastomeric material is:
 - a) in an uncompressed state, or
 - b) in a precompressed state, and
 - (ii) said second surface area when said compressible elastomeric material is in its compressed state as a result of freeze expansion of said aqueous liquid.
6. The conduit of claim 5 wherein said conduit forms part of a solar thermal collector.

7. The conduit of claim 5, wherein said compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber and urethane foam.
8. A conduit for conveying or containing aqueous liquids, comprising a substantially liquid impermeable flexible membrane for defining a liquid passage, wherein said membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, said compressible elastomeric material being supported by a rigid support member, said rigid support member being liquid permeable.
9. The conduit of claim 8, wherein said rigid support member comprises perforations for facilitating external drainage of liquid.
10. The conduit of claim 8, wherein said conduit forms part of a solar thermal collector.
11. The conduit of claim 8, wherein said compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber and urethane foam.
12. The conduit of claim 8 wherein said membrane has a first surface characterized by a first surface area, and said compressible elastomeric material has a second surface characterized by a second surface area, said first surface being in substantially adjacent relationship with said second surface, said first surface area exceeding the greater of:
- (i) said second surface area, when said liquid passage contains no liquid and said compressible elastomeric material is:
- a) in an uncompressed state, or
- b) in a precompressed state, and
- (ii) said second surface area when said compressible elastomeric material is in its compressed state as a result of freeze expansion of said aqueous liquid.
13. A conduit for conveying or containing aqueous liquids, comprising a substantially liquid impermeable flexible membrane for defining a liquid passage, wherein said membrane is disposed in substantially adjacent relationship with a compressible elastomeric material, and wherein said membrane has a first surface characterized by a first surface area, and said compressible elastomeric material has a second surface characterized by a second surface area, said first surface being in substantially adjacent relationship with said second surface, said first surface area exceeding the greater of:

- (i) said second surface area, when said liquid passage contains no liquid and said compressible elastomeric material is:
- a) in an uncompressed state, or
 - b) in a precompressed state, and
- 5 (ii) said second surface area when said compressible elastomeric material is in its compressed state as a result of freeze expansion of said aqueous liquid.
14. The conduit of claim 13, wherein said conduit forms part of a solar thermal collector.
15. The conduit of claim 13, wherein said compressible elastomeric material is selected from the group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge
- 10 rubber and urethane foam.
16. A conduit for conveying or containing aqueous liquids comprising a substantially liquid impermeable flexible membrane for defining a liquid passage, said membrane being disposed in substantially adjacent relationship with a compressible elastomeric material, said membrane including a first portion and a second portion wherein an exterior of said first
- 15 portion is disposed in substantially adjacent relationship with a first rigid structural support member and an exterior of said second portion is disposed in substantially adjacent relationship with a compressible elastomeric material.
17. The conduit of claim 16, wherein said conduit forms part of a solar thermal collector.
18. The conduit of claim 16, wherein said compressible elastomeric material is selected from the
- 20 group consisting of foamed butyl rubber, foamed neoprene, silicone foam, silicone sponge rubber and urethane foam.
19. The conduit of claim 16, wherein said compressible elastomeric material is supported by a second rigid structural support member and said member is liquid permeable for external drainage of aqueous liquid.
- 25 20. The conduit of claim 16, wherein said membrane has a first surface characterized by a first surface area, and said compressible elastomeric material has a second surface characterized by a second surface area, said first surface being in substantially adjacent relationship with said second surface, said first surface area exceeding the greater of:
- (i) said second surface area, when said liquid passage contains no liquid and said compressible
- 30 elastomeric material is:
- a) in an uncompressed state, or
 - b) in a precompressed state, and

- (ii) said second surface area when said compressible elastomeric material is in its compressed state as a result of freeze expansion of said aqueous liquid.
21. A conduit for conveying or containing aqueous liquids comprising a substantially liquid impermeable flexible membrane for defining a liquid passage, said membrane being disposed in substantially adjacent relationship with a compressible elastomeric material, said membrane and said compressible elastomeric material supported by a rigid support member wherein said rigid support member is formed from a single sheet having a first edge and a second edge joined by a width, said single sheet being bent proximate said first edge to form a hem and a flap, said first edge being rolled over itself to form an interior rolled-over surface portion, said single sheet further provided with a first bend along said width, said membrane and said compressible elastomeric material being substantially contained by said interior rolled-over surface portion, said first bend being disposed between said hem and said second edge, said flap being disposed within said first bend to form a lock.
22. The conduit of claim 21, wherein said first bend joins a first portion of said width to a second portion of said width, said first portion and said second portion extending from said first bend, said flap being inserted and pressed between said first portion and said second portion whereby said flap lockingly engages said first bend.
23. The conduit of claim 22, wherein said lock is liquid permeable.
24. The conduit of claim 23, wherein said hem contacts a surface of said width to form a seam.
25. The conduit of claim 24, wherein said compressible elastomeric material is disposed between said seam and said membrane.
26. The conduit of claim 25, wherein said seam is liquid permeable.
27. The conduit of claim 21, wherein said single sheet is further provided with a second bend disposed between said first bend and said second edge, said second bend joining a third portion of said width to a fourth portion of said width, said third portion and said fourth portion extending from said second bend, said fourth portion forming an absorber plate in a solar thermal collector.
28. A method of constructing a freeze protected conduit for conveying or containing aqueous liquids comprising the steps of:
- (i) bending a single sheet having a first edge and a second edge joined by a width to form a hem and a flap proximate said first edge;
- (ii) rolling said first edge over itself to form an interior rolled-over surface portion;

- (iii) bending said sheet at a first point along said width between said hem and said second edge to form a first bend, said first bend joining a first width portion and a second width portion, said first width portion and said second width portion extending from said first bend;
- (iv) inlaying a flexible conduit and compressible elastomeric material against said interior rolled-over surface portion for effecting containment and support of said flexible conduit and said elastomeric material; and
- (v) pressing said flap between said first width portion and said second width portion to form a lock.
29. The method of claim 28, wherein step (iv) must occur before step (v) and after step (ii), and wherein step (iii) must occur before step (v).
30. The method of claim 28, wherein said hem contacts a second point along said width of said sheet during step (ii).
31. A freeze protected conduit for conveying or containing aqueous liquids, defining a liquid passage, comprising a substantially liquid impermeable membrane disposed in substantially adjacent relationship with a compressible elastomeric material, wherein said membrane comprises silicone rubber.
32. The conduit of claim 31, wherein said membrane has a thickness within the range of about 0.007 inches to about 0.020 inches.
33. The conduit of claim 31, wherein said conduit is used in heat transfer applications.

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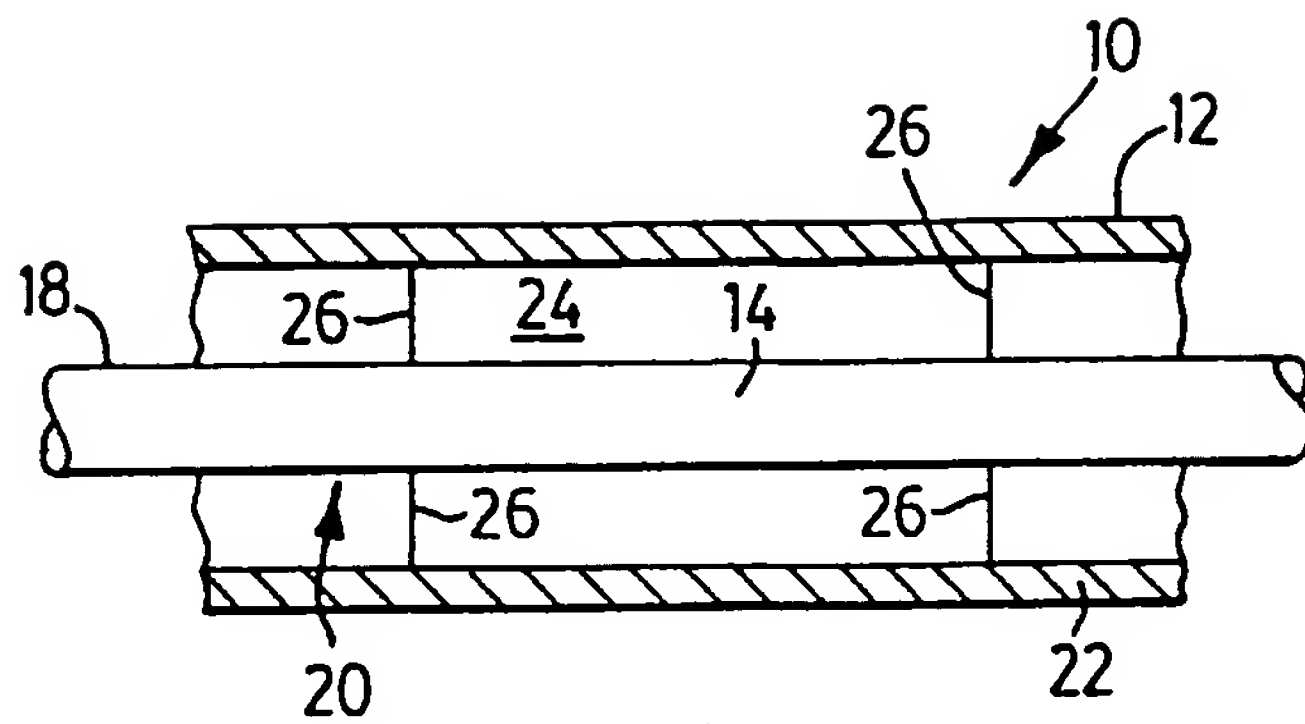


FIG. 1

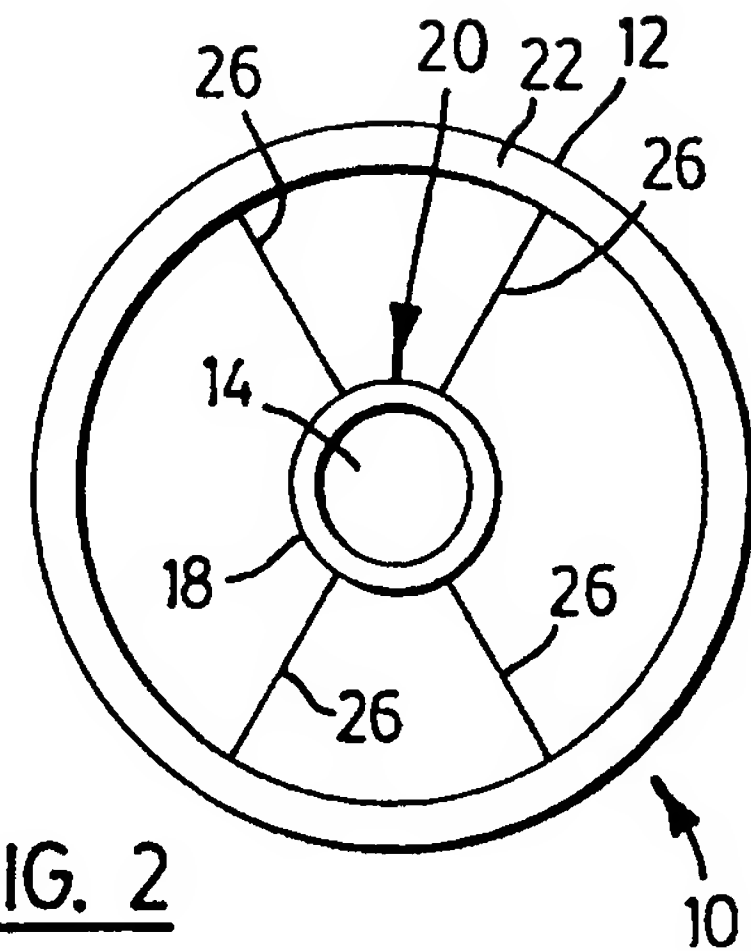


FIG. 2

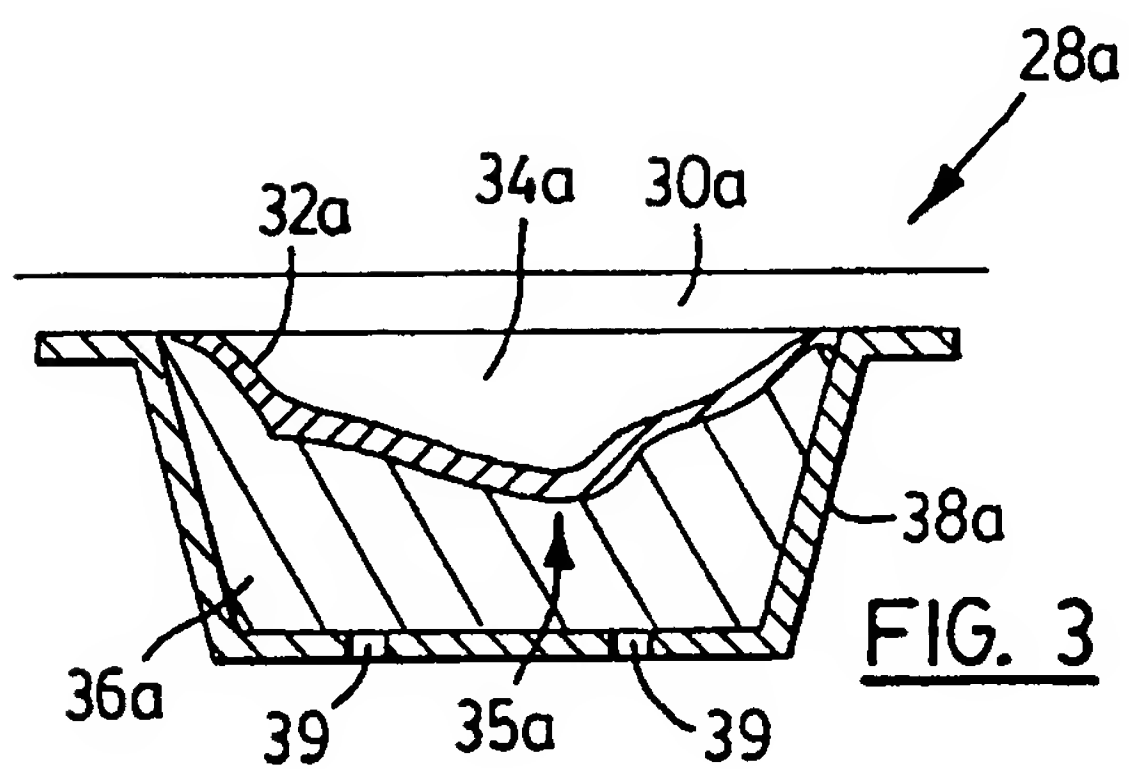


FIG. 3

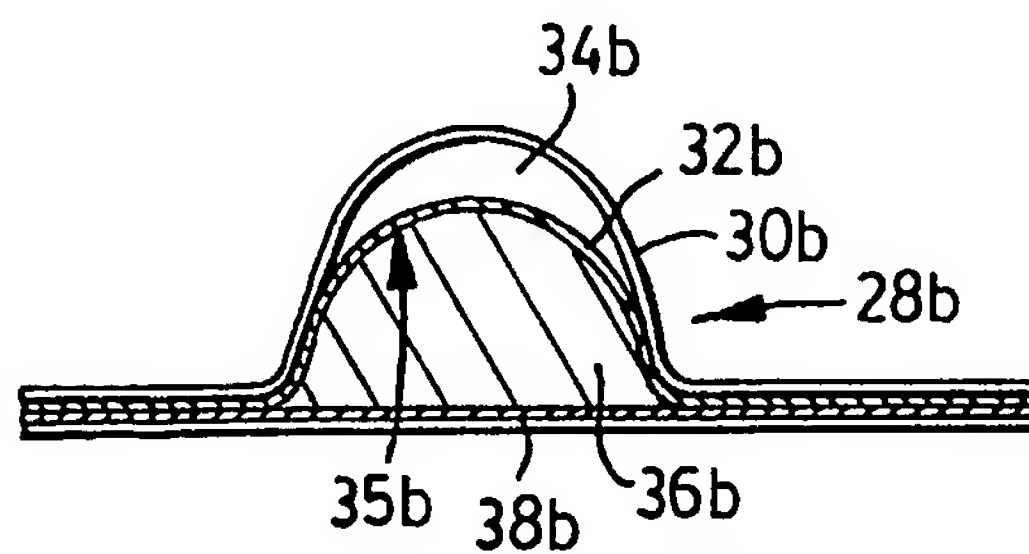
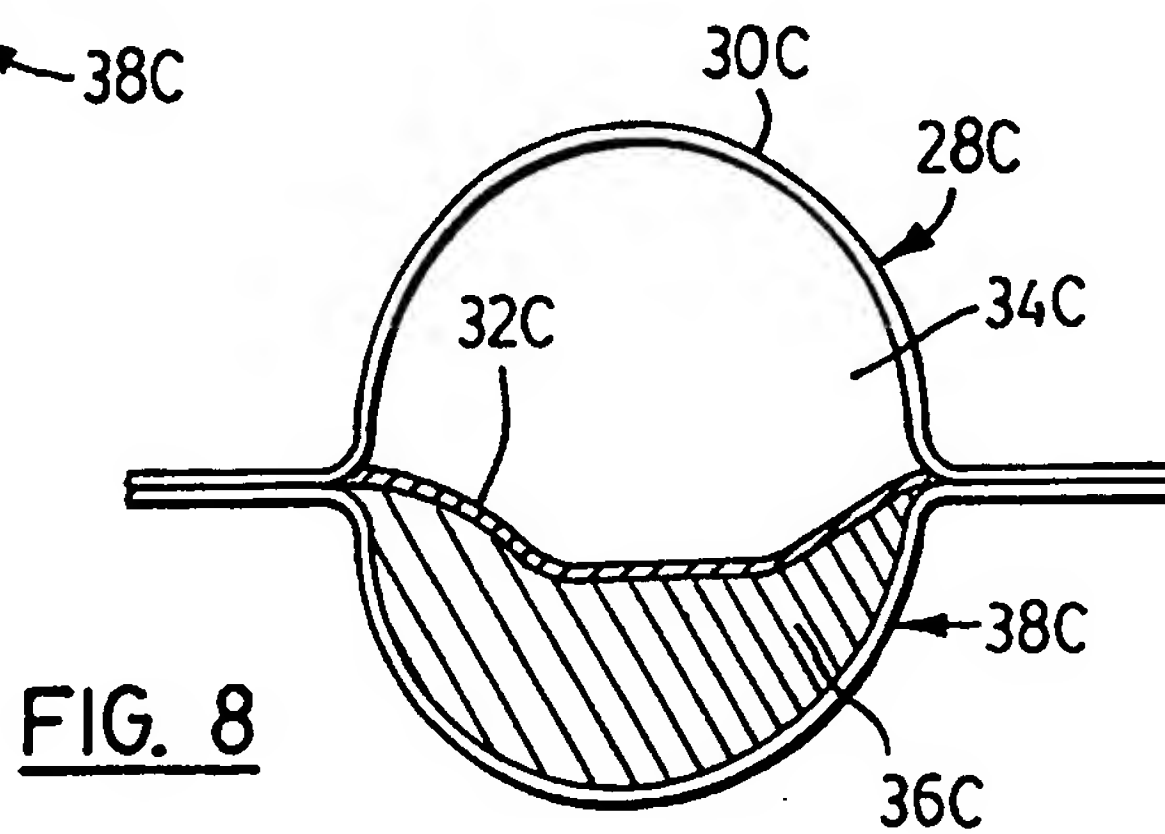
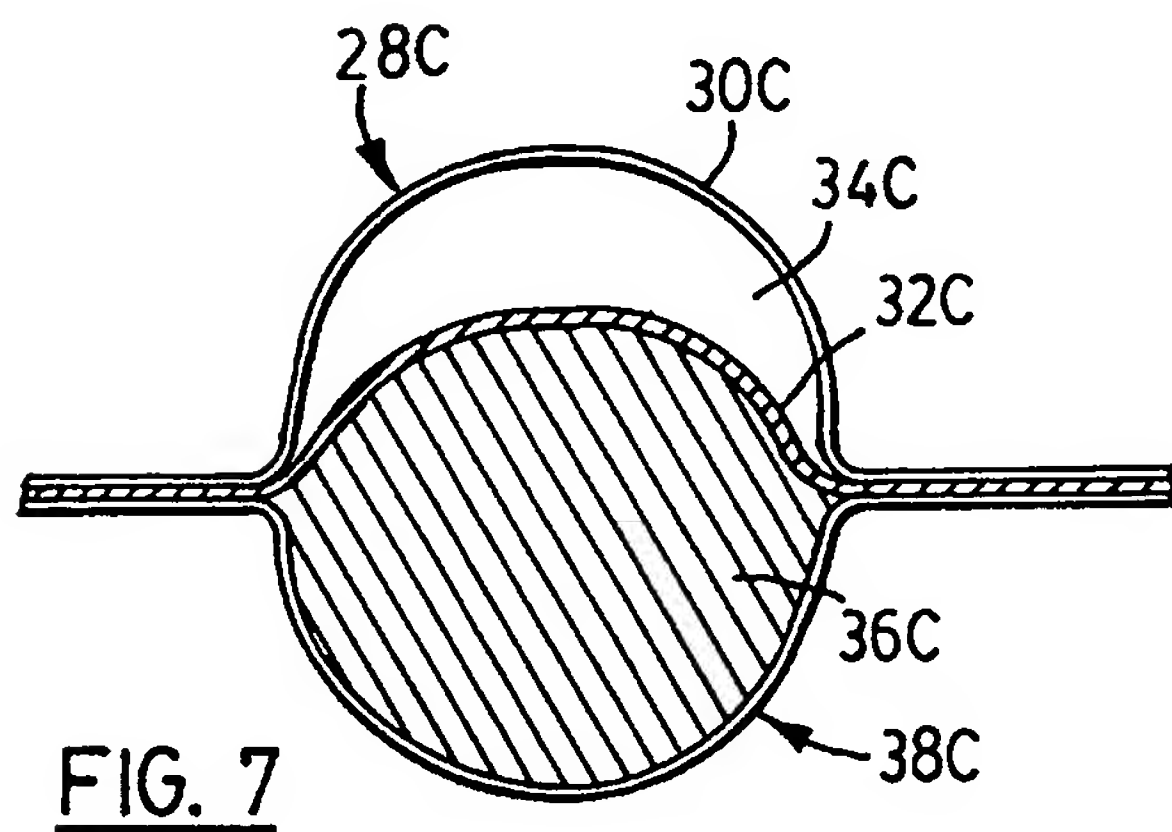
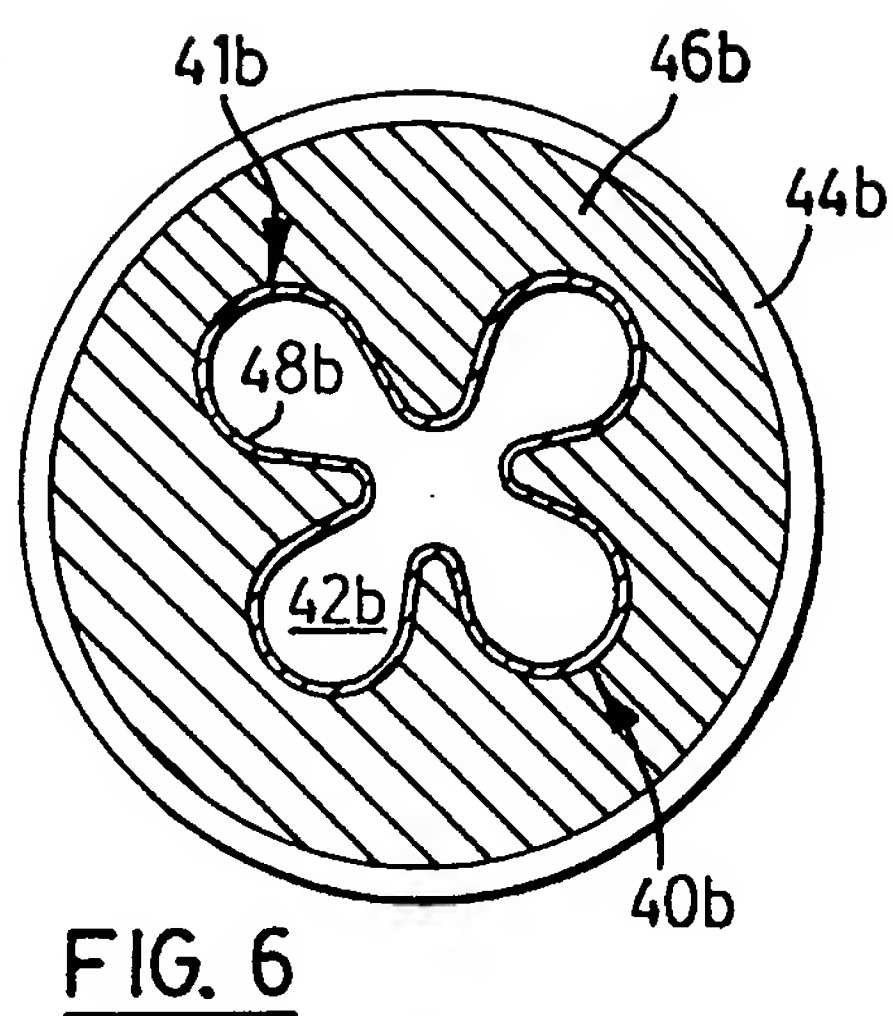
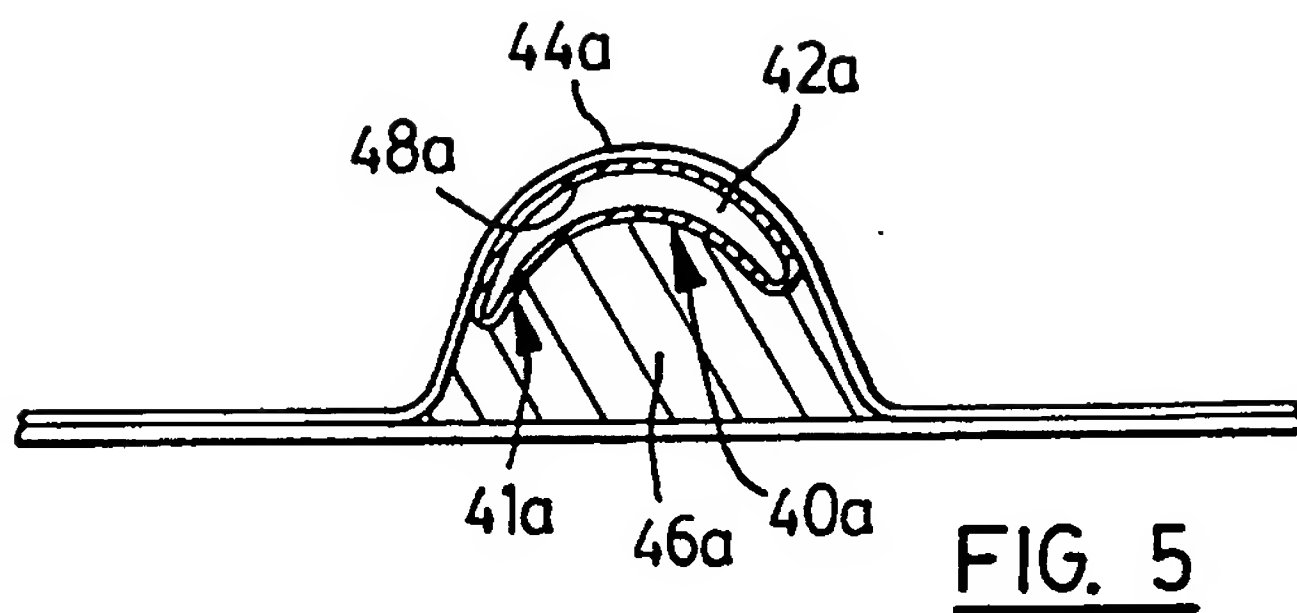


FIG. 4

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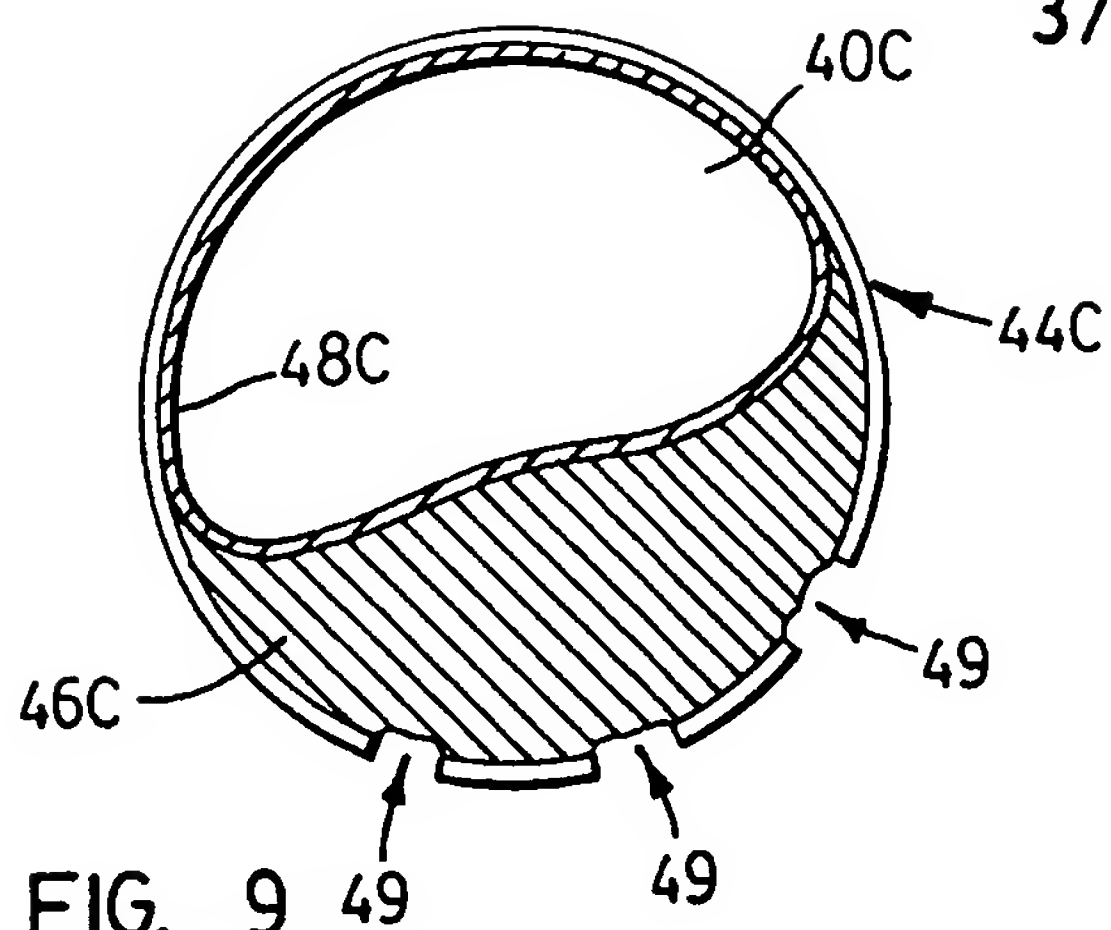


FIG. 9

FIG. 10

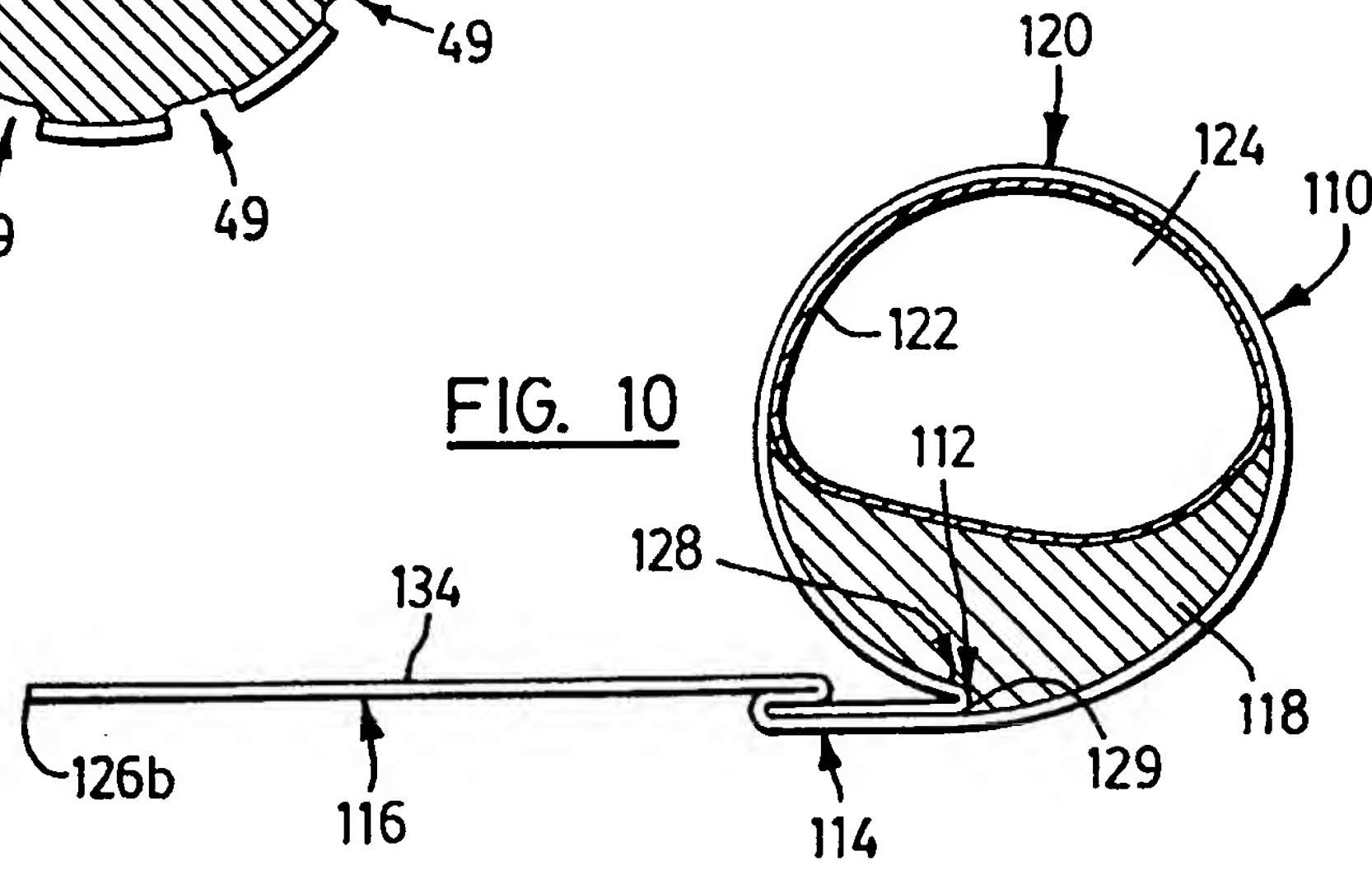


FIG. 11

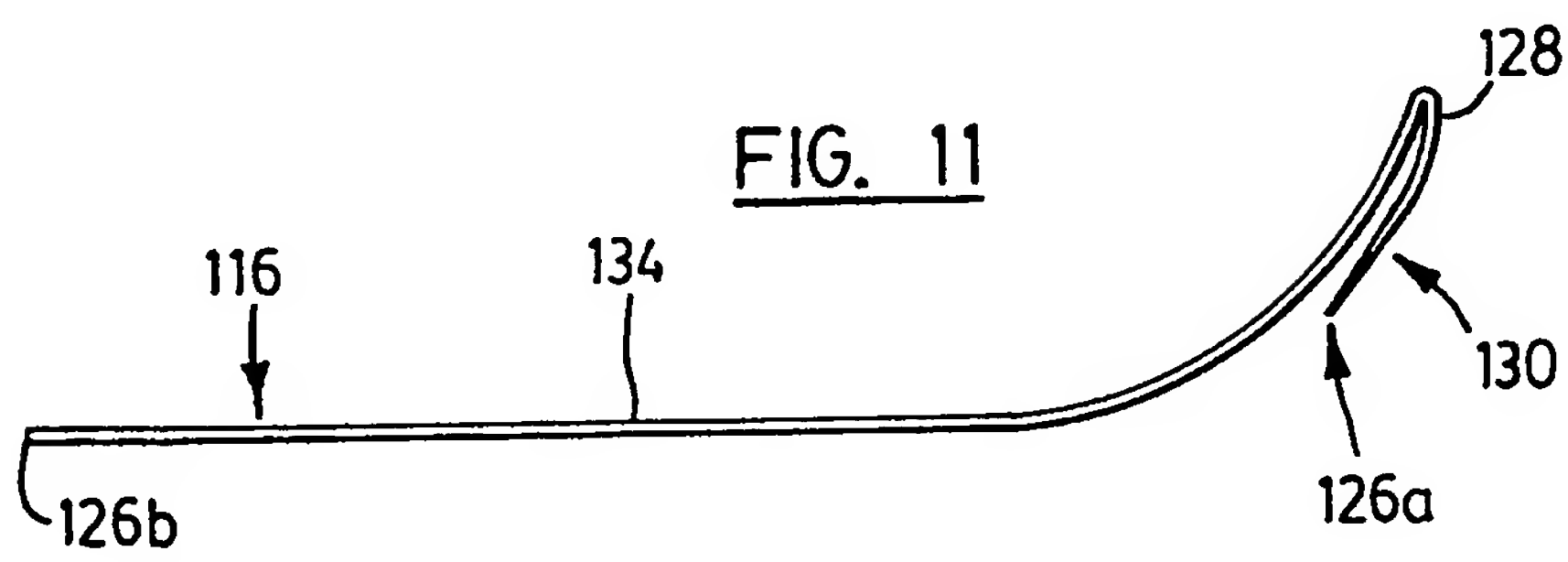
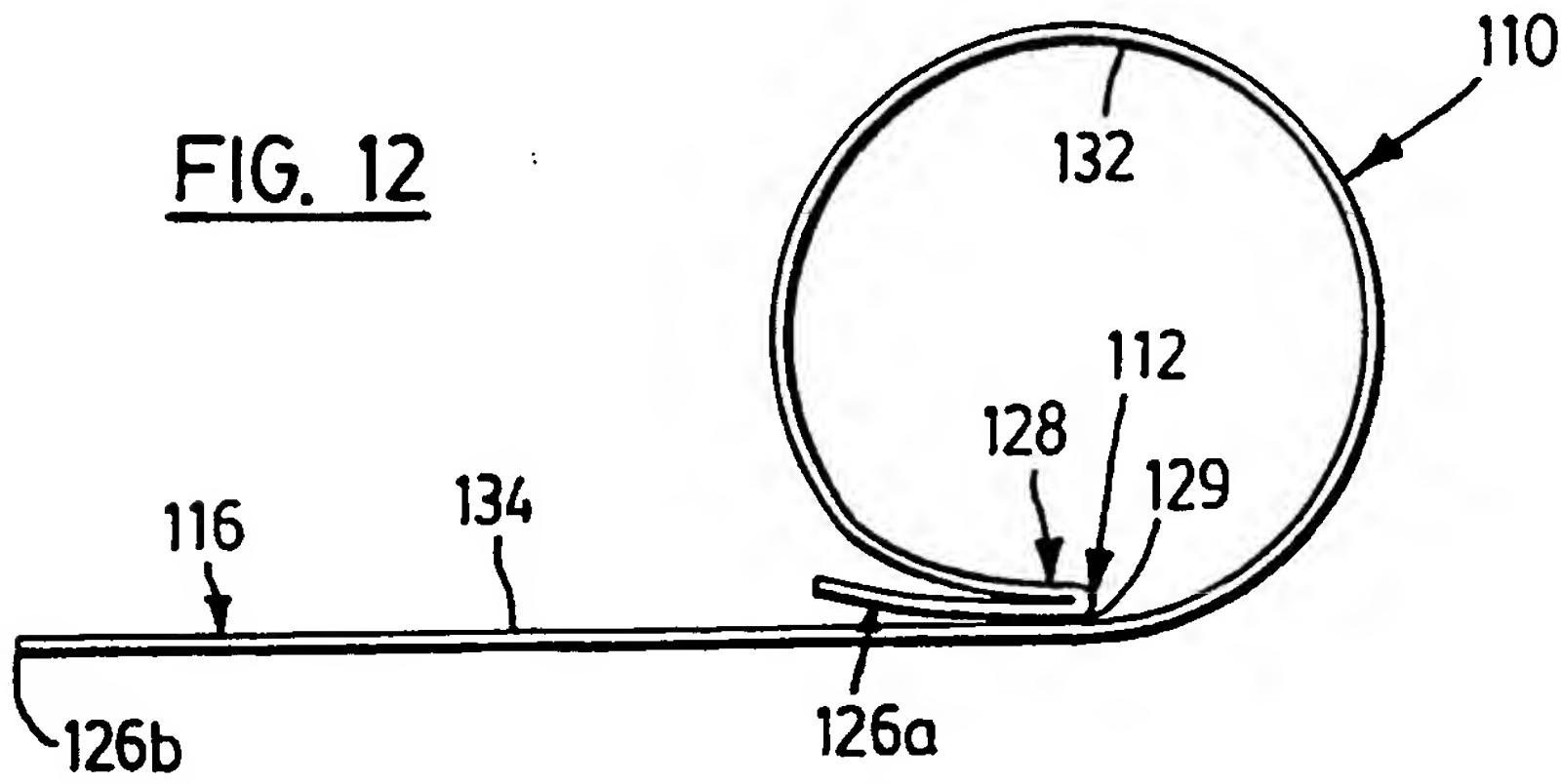


FIG. 12



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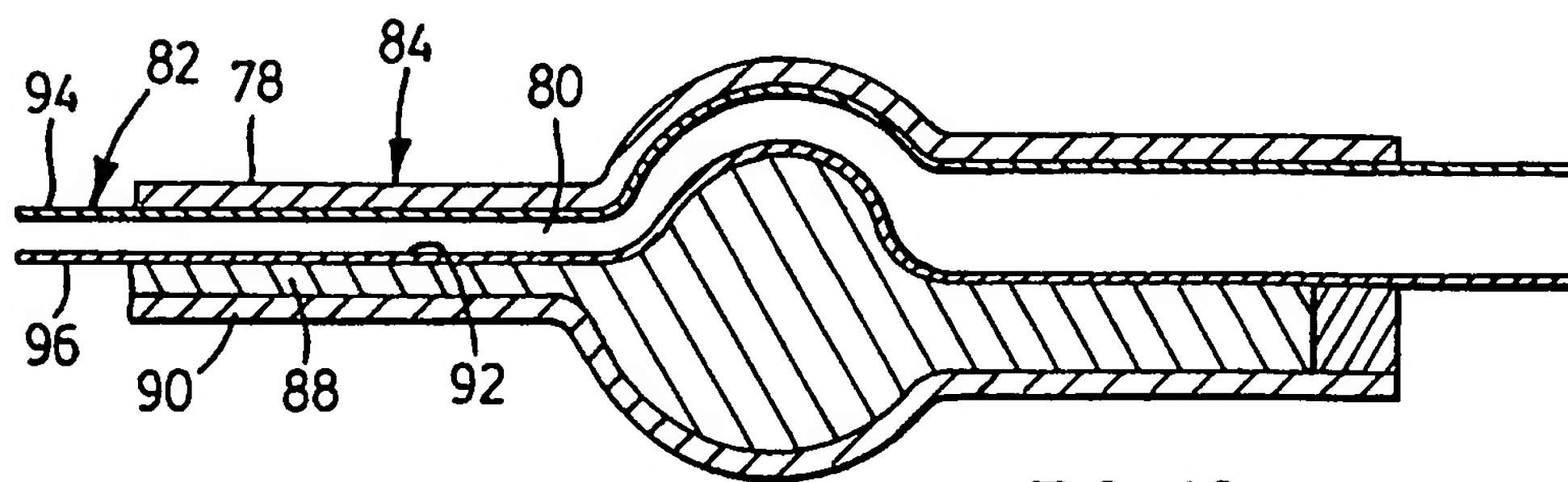
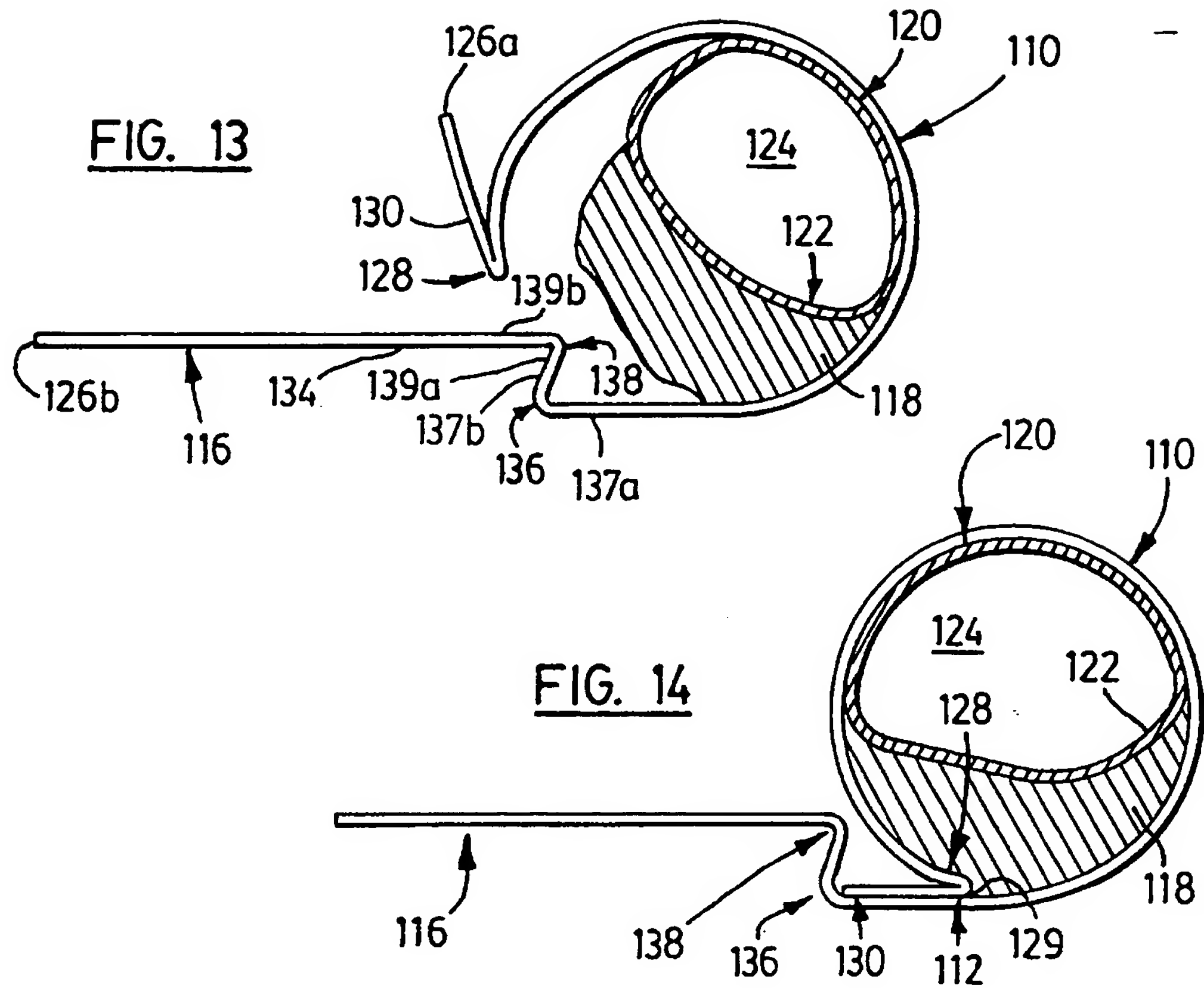
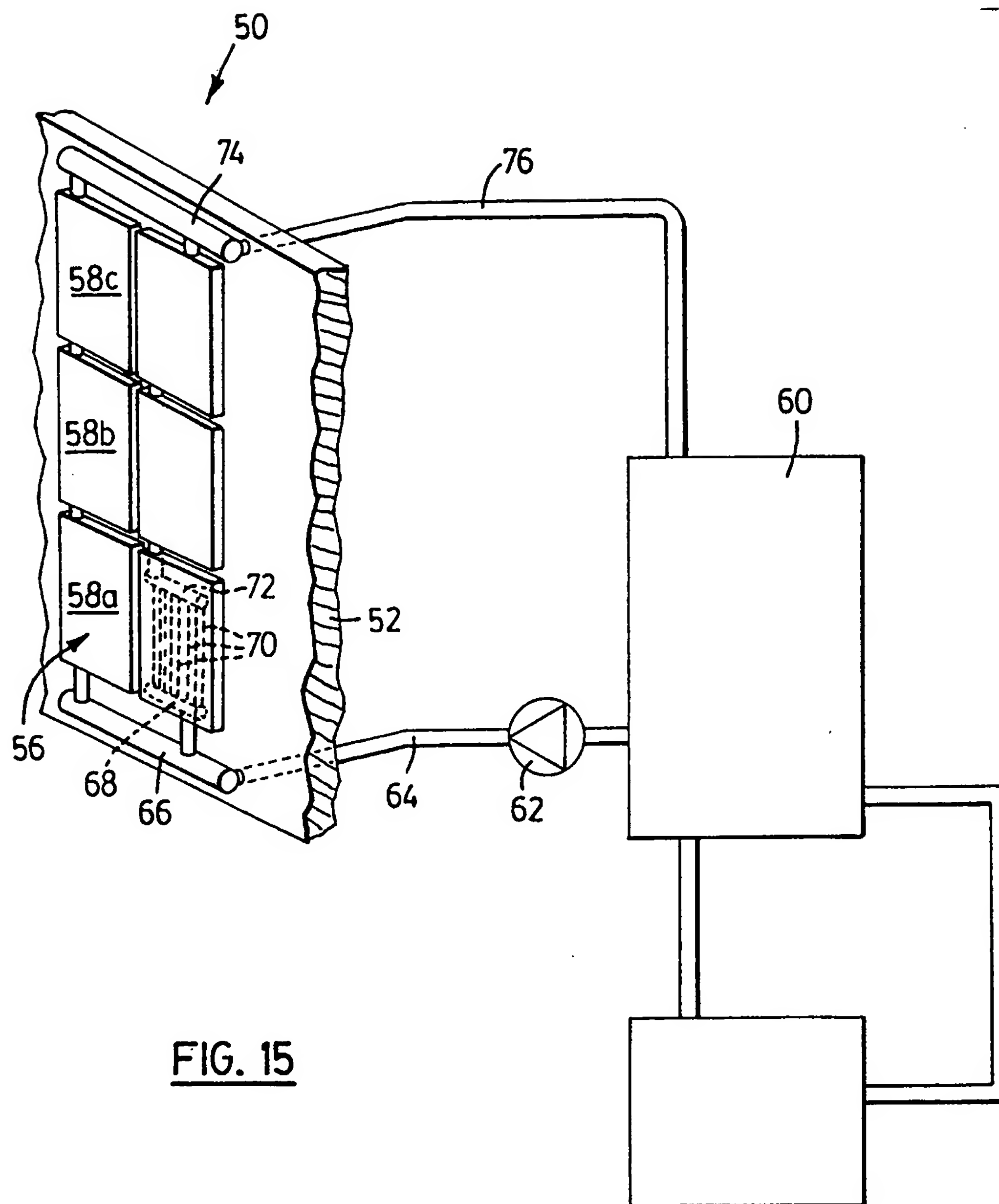


FIG. 16

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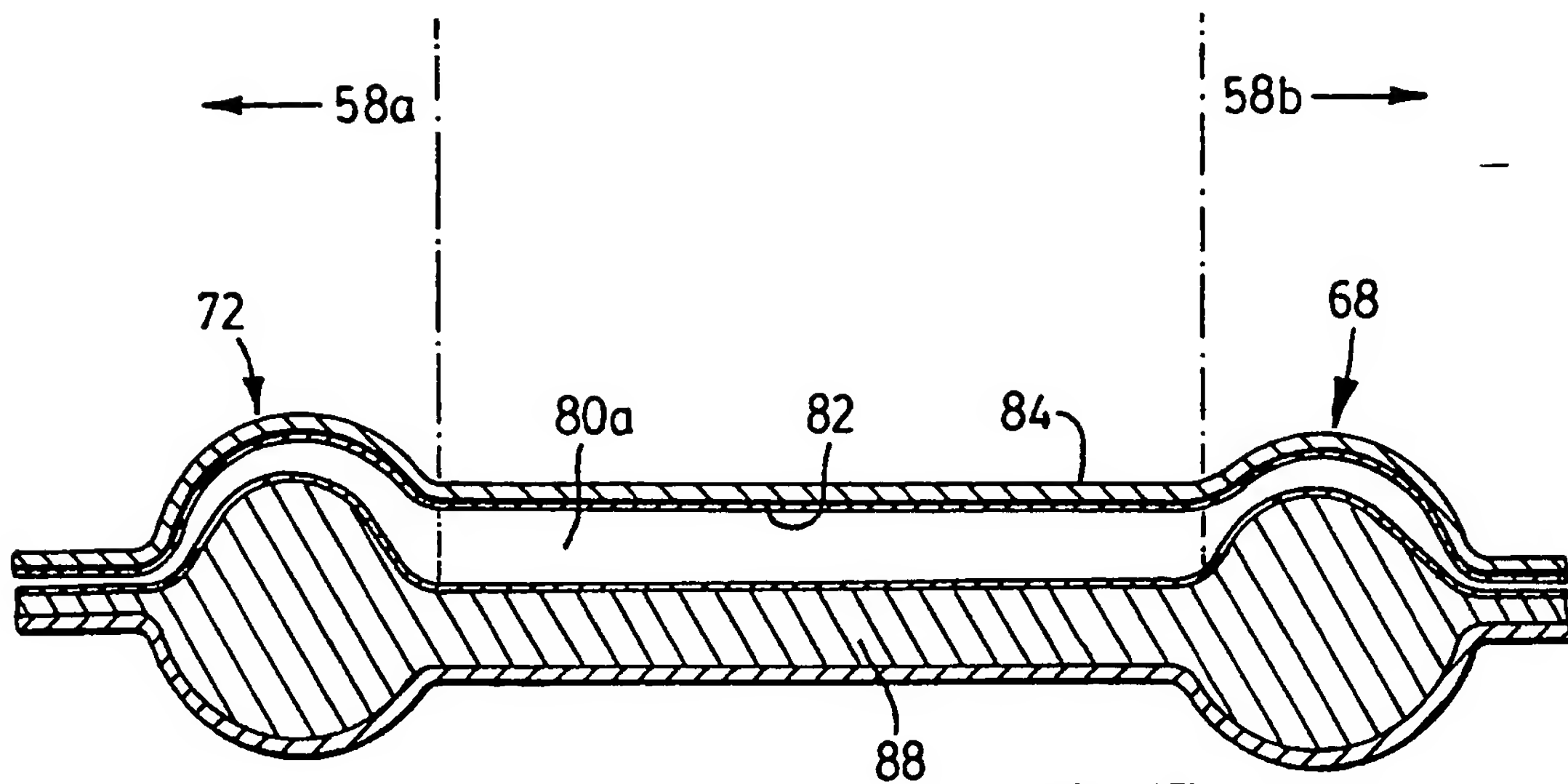


FIG. 17

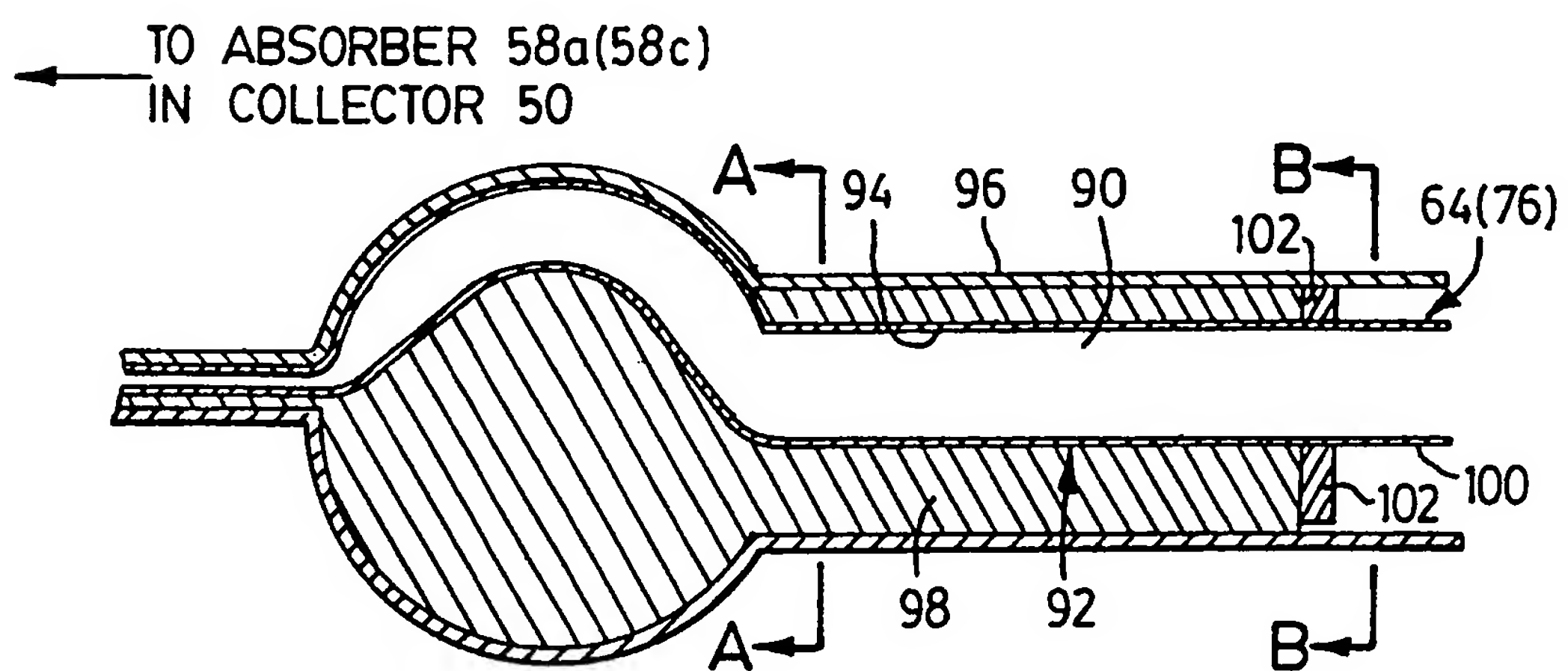


FIG. 18

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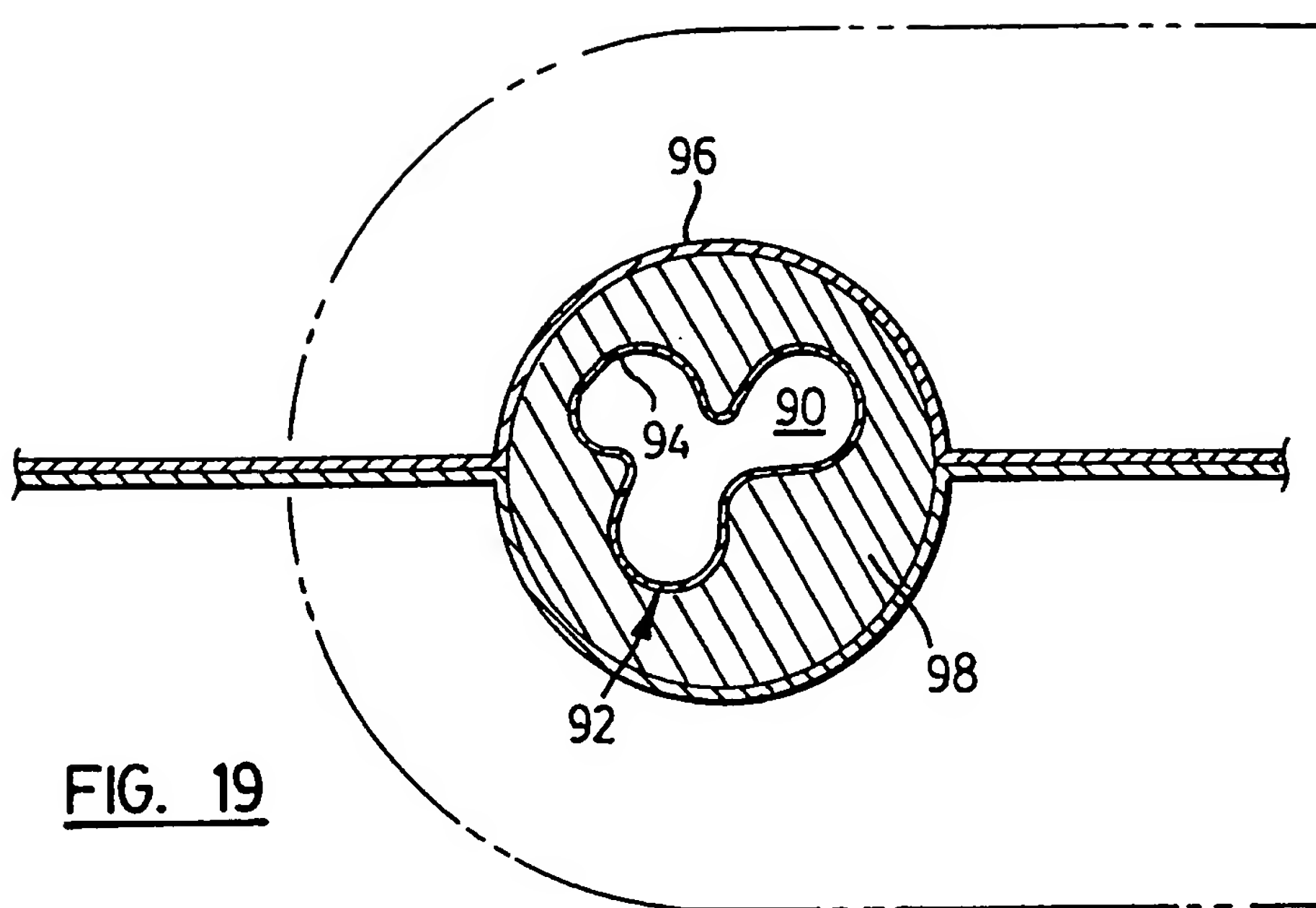


FIG. 19

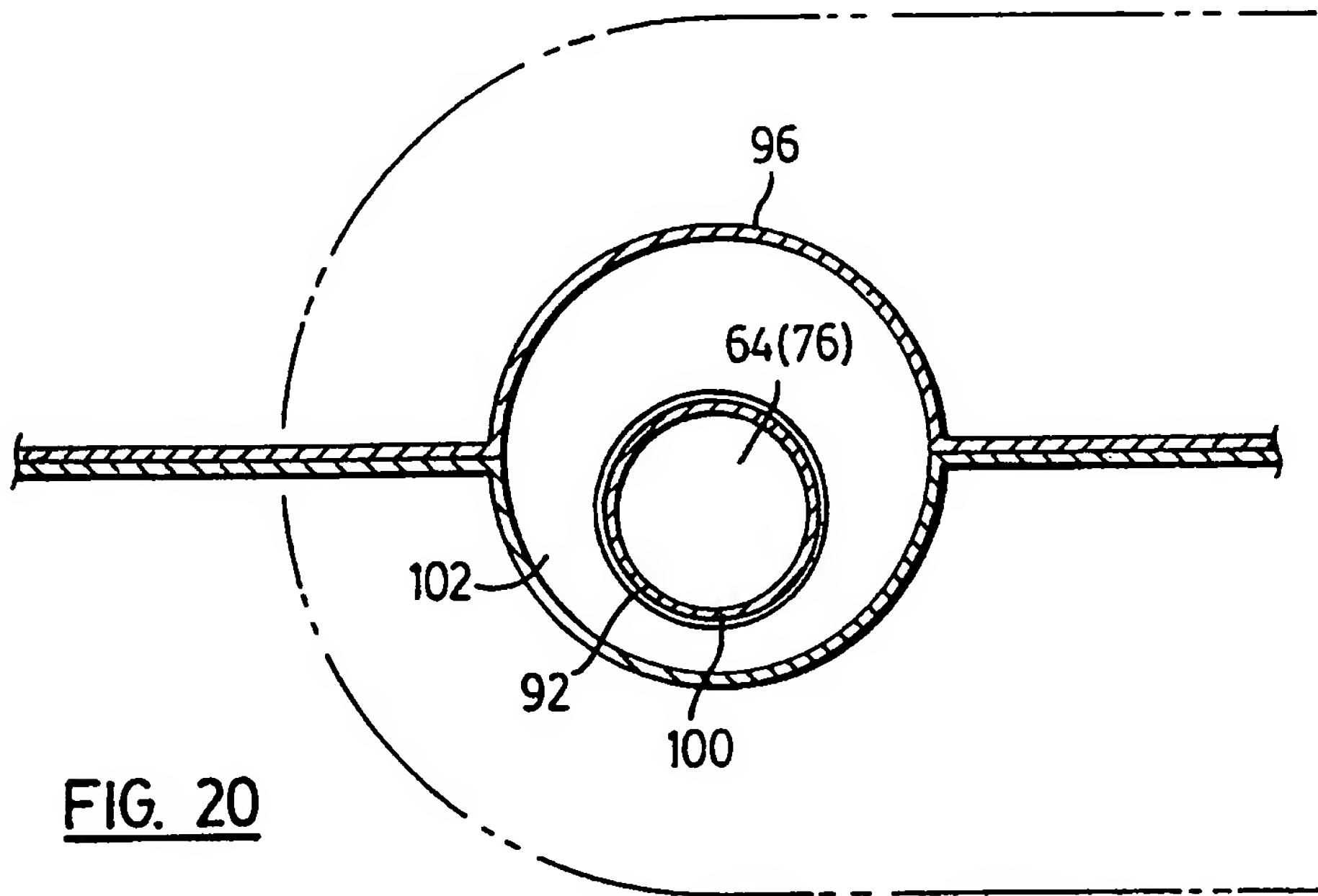


FIG. 20

INTERNATIONAL SEARCH REPORT

Int. Application No.

PCT/CA 99/00824

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 F24J2/46 E03B7/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 F24J E03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	FR 2 478 161 A (FABRE JEAN) 18 September 1981 (1981-09-18) page 4, line 3 - line 4 page 4, line 30 - page 5, line 20 page 7, line 1 - line 8; figures	16-18, 31, 33 1-15
X A	GB 2 167 827 A (RICHMOND JOHN HENRY) 4 June 1986 (1986-06-04) page 1, line 33 - page 2, line 14 page 2, line 24 - line 29; figures; tables	16, 31 1-20, 32
X	US 1 927 105 A (SOLOMON J. WELCH) 19 September 1933 (1933-09-19) the whole document	31
A	CH 512 043 A (ABIG GMBH) 31 August 1971 (1971-08-31) the whole document	1-20, 31-33
-/-		

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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- "Z" document member of the same patent family

Date of the actual completion of the international search

19 November 1999

Date of mailing of the international search report

30/11/1999

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MOOTZ, F

INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 99/00824

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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